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CO_2 emission and avoidance in mobile applications

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ABSTRACT

The present paper analyzes the CO_2 emissions from mobile communications and portable wireless electronic devices in the Korea environment. The quantitative and qualitative contributions to CO_2 emission reduction of the substitution of renewable energy for traditional electricity as the power supply in these devices are also investigated.

Firstly, the national CO_2 emission coefficient is temporarily estimated as 0.504 tCO_2/MWh, which can be regarded as the basis for calculating CO_2 emissions in mobile devices. The total annual CO_2 emissions from mobile devices is calculated as approximately 1.4 million tons, comprising 0.3 million tCO_2 for portable wireless electronic devices and 1.1 million tCO_2 for electric equipment required for mobile communication service.

If renewable energy sources are substituted for traditional electricity sources in the supply for mobile devices, solar cell and wind turbine systems can reduce CO_2 emissions by about 87% and 97%, respectively. However, the use of fuel cell systems will only slightly reduce the CO_2 emissions. However, the use of the direct methanol fuel cell system can release 8% more CO_2 emissions than that emitted by using traditional electricity sources.

Contents

1. Introduction

In today's ubiquitous and highly developed, wireless networked society, the market for information technology (IT) devices such as mobile phones, computers, and many other portable wireless electronic devices has rapidly expanded. Mobile

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Table 1
Various assumptions used to calculate CO_2 emissions from mobile wireless electronic devices [3–6].

Portable devices	Average power output (W)	Average operation time/day (h)	Average operation time/year (h)	Number of units (million)	Features
Laptop	20	8	2,920	5.6	-5–17 in. TFT LCD display - Li-battery; (10.8V/4800 mAh)
Mobile phone (2G–2.5G)	1.5 (use)	1.17 0.17 (Talk) 1 (Other service)	426	21.5	- 2.2–2.8 in. TFT-LCD display -3.7 V/800–1000 mAh - 2Mega pixel digital Camera, MP3 on-board - Talk, message, restricted data communication, Global roaming and DMB
	0.01 (Stand-by)	22.83	8,334		
Mobile Phone (3G–3.5G)	2.0 (use)	2.17 0.17 (Talk) 1 (Other service) 1 (DMB or browsing)	791	21.5	- 3–3.5 in. TFT-LCD touch-screen display - 3.7 V/1000–1500 mAh - Including all functions of 2G services - Global multimedia, video call and VGA camera, Internet browsing, DMB, Maps, GPS and PDA on-board
	0.01 (stand-by)	21.83	7,969		
Others	Referred to Table 2	1	8,760	Referred to Table 2	PDA, PMP, MP3, digital book (electronic dictionary), digital camera, camcorder, CDP, video game consoles

wireless technologies are being developed very quickly due to their advantages. In addition, various mobile communication and Internet services have been already provided in Korea, including Wireless Broadband (WiBro), Digital Multimedia Broadcasting (DMB), visual phone call and mobile banking.

The current power supply systems in portable wireless electronics are mostly rechargeable lithium (Li-ion or Li-polymer) battery systems. The dominance of Li battery systems compared to other battery systems will continue in the near future due to their superior features. Nevertheless, the electricity required to charge the Li battery system must be supplied by the centralized power grid, which is typically sourced from thermal power stations with high carbon-dioxide (CO_2) emissions.

Therefore, the mobile wireless electronic devices using rechargeable batteries are direct CO_2 emission sources. However, the relatively tiny power requirements of devices such as cellular phones, laptop computers and MP3 players output might suggest that they add an insignificant load to the total CO_2 emissions. Nevertheless, a tremendous number of these devices might render their CO_2 emissions more than negligible.

In addition to the direct CO_2 emissions from mobile devices, they also incur further emissions from the infrastructures widely dispersed over the country for mobile communication services, including data centers and various electric equipments such as mobile base stations, repeaters and switches, as well as wireless LAN stations. Furthermore, as stated earlier, the number of these devices will greatly increase in the future. Therefore, CO_2 emissions from mobile devices are currently a significant issue and will assume increasing importance in the field of CO_2 emission mitigation.

With increased awareness of the dangers of climate change due to greenhouse-gas (GHG) emissions, attention is focused world-wide on decreasing CO_2 emissions [1]. Therefore, the reduction of CO_2 emissions from IT fields has gained attention. According to the Gatner report [2] in 2007, the GHG emissions from the global IT industries were about 2% of total global CO_2 emissions. The application of this ratio in Korea would suggest annual CO_2 emissions from the IT industry of about 12 million tons, which is 20% more than those from high-energy consuming chemical processes such as naphtha cracking for olefin production. In addition, the rate of increase in CO_2 emissions from the IT industry is markedly faster than that of any other field due to the very rapid developments of this ubiquitous industry.

Among the various IT fields, CO_2 emissions from mobile devices, including mobile communication and Internet, as well as portable wireless electronic devices, are increasing more than any other field. Nevertheless, the amount of CO_2 emissions from this field has neither been estimated nor even investigated.

Therefore, the present paper quantitatively and qualitatively analyzes the CO_2 emissions from mobile devices in Korea. These CO_2 emissions result from the electricity generated to charge the batteries for the mobile electronic devices. CO_2 emissions resulting due to the generation of electricity required to operate the electric equipment for mobile communication such as mobile base stations, repeaters and switches, as well as wireless LAN stations are also included.

This paper also investigates the possible reduction in CO_2 emissions gained by substituting various renewable energy sources, such as solar cell (photovoltaic), wind turbine and fuel cells, for traditional electricity generation. Therefore, this paper might provide useful information to mitigate the CO_2 emissions from mobile devices.

2. Assumptions for estimation of CO_2 emissions

2.1. Mobile wireless electronic devices

The estimation of the CO_2 emissions from the mobile devices begins with the various assumptions on mobile wireless electronic devices, as listed in Table 1.

The portable devices are divided into four categories: laptop computers, 2–2.5G (Generation) mobile phones, 3–3.5G mobile phones (including Smart phone) and other devices including PDA, PMP, MP3. The various data of these devices such as average power output and favorable operation time must be estimated. Mobile devices are not always operated in a wireless state. For example, laptop computers are often used indoors and plugged into the mains or outdoors on battery supply. The electricity consumption and CO_2 emissions will differ between these two cases due to their different energy losses. In present paper, however, it is assumed that every mobile electronic device solely uses the charged battery as the power supply.

Finally, the number of individual mobile devices in Korea is estimated. All the assumed data on the mobile devices are summarized in Table 1. Detailed descriptions on the background of these assumed values are presented in the subsequent section.

2.1.1. Laptop computer

The average power output and operational time of the laptop computers were assumed to be 20 W and 8 h per day, respectively. Eight hours per day was the most favored operating time for Korean users [3] and the stand-by time was neglected. In Korea, about 5.6 million laptop computers were sold in the 4-year period of 2005–2008 and this was considered the number of currently working laptops. It is assumed that the most laptops use Li-ion (or polymer) batteries of which energy capacity is 51.84 Wh (10.8 V $\times$ 4800 mAh) on average.

2.1.2. Mobile phone

As well as the traditional cellular phone uses of talking and sending messages, mobile phones have evolved into multiple electronic devices for watching TV, Internet browsing, video talking, phone banking, paying and ticketing. These services are widely offered and used in Korea. Therefore, mobile phones must be classified into two categories, 2G (including 2.5G phones) and 3G (including 3.5G phones), before the electricity consumption can be estimated.

Their features are listed in Table 1. The traditional 2G cellular phone is used for data communication, DMB and global roaming. On the other hand, the 3G phone, including smart phone and iphone, generally has a 3–3.5 in. TFT-LCD touch-screen display and offers extra functions that enable video calls and high speed browsing like PCs. Furthermore, GPS, PDA and VGA camera are included.

Their power output consumptions for talk and other services are assumed to be 1.5 and 2.0 W for 2G and 3G phone, respectively. It is also assumed that they consume the same, 0.01 W for stand-by mode. According to a survey [4,5], Korean people consume 5 h per month for phone talking on average and spend about 1 h per day on other services. Meanwhile, 3G phone users additionally use one more hour for watching TV (DMB) or Internet browsing. In the remaining time, the mobile phone is in the state of stand-by mode with the average power output of 0.01 W.

Based on the data released by telecommunication companies in early 2008, it is assumed that the total number of mobile phone users is 43 million, half of whom use the 3G phone [6].

2.1.3. Other mobile devices

The other mobile wireless devices included in the study comprise the eight items that are listed in Table 2. GPS and navigator were not considered because their energy source is the automobile engine.

The market for some of these other devices has shrunk or stagnated because their functions have recently been absorbed into the 3G mobile phone. The numbers of units of each of these eight devices currently in use in Korea are estimated in Table 2. These estimations were roughly based on data from magazines, newspapers and company reports [7,8]. Based on an assumed lifespan of 4 years, the total sales for the 4-year period of 2005–2008 were used. The power output was assumed to be 1.5-fold more than that claimed by the manufacturers. Meanwhile, the average operational time of each device was assumed to be 1 h per day.

2.2. Batteries for mobile wireless electronic devices

In this paper, all mobile devices were assumed to use the rechargeable Li-ion battery system. To calculate the exact electricity consumption in Li-ion battery systems, the energy losses should be considered. These include loss of energy capacity of battery due to repeated charge–discharge cycles (or charge–discharge efficiency), and loss of electricity from the adaptor in the charging process [3]. These values are listed in Table 3.

The energy loss by using the rechargeable battery is assumed to be 30% more than that by using mains electricity, which equates to 30% more CO_2 emissions. Meanwhile, the self-discharge of the batteries and the electricity loss due to the transmission from the power generation plant to house are neglected.

2.3. Electric equipment for mobile communications

The operation of the various mobile communication devices such as mobile phone, Internet and DMB requires a tremendous infrastructure of electrical service equipment including data centers, mobile base stations, repeaters and switches. However, the present paper only considers base station and repeaters because of the negligible electricity consumed by data center and switches.

Currently, three kinds of base station and repeater are used in the mobile communication field: mobile phone, Internet (WiBro) and DMB. Their assumed numbers and average power output, which are based on the reliable domestic data, are listed in Table 4.

3. CO_2 emission coefficient due to electricity generation

The nation's CO_2 emission coefficient (NCEC) due to electricity generation was estimated by the government based on the nation's various energy data as 0.424 tCO_2/MWh in 2003. The coefficient may not be exact because the current proportions of the electricity sources are not the same as in 2003.

Therefore, in present paper, an NCEC value was temporarily calculated and simply estimated based on various data such as the amount of the nation's electricity generation according to the fuel

Table 2
Various assumptions used to calculate CO_2 emissions from 8 other portable electronic devices.

Portable devices	Average power output claimed by manufacture (W)	Average power output (W)	Number of units	Features
Camcorder	4.5	6.75	400,000	–
CDP	1	1.5	200,000	–
Digital camera	1	1.5	8,000,000	- Including function of video recording and playing
e-book	3	4.5	4,800,000	- Including e-dictionary, e-photo album, e-picture frame
MP3	0.5	0.75	8,000,000	–
PDA	2	3	260,000	–
PMP	2	3	2,440,000	–
Video game consoles	2		2,000,000	–
Total			26,100,000	–

Table 3
Assumptions used to calculate the electricity loss of a Li-ion battery system using power supply of the portable wireless electronic devices.

Electricity loss	Value
Average loss of battery efficiency (or energy capacity) according to repeated charge–discharge cycle	80% (from initial use to end of life) of energy capacity
Loss of electricity from the adaptor in charging process	10% of energy capacity
Self-discharge	Neglected
Electricity transmission loss	Neglected

sources, and individual CEC value of power plant as listed in Table 5.

The total electricity generation and compositions according to fuel sources are shown in Table 5 and Fig. 1.

The NCEC is estimated by considering the individual CEC values for each fuel source. Two sets of values, from the Korea Electric Power Corporation (KEPCO) and the International Atomic Energy Agency (IAEA), are listed for each fuel source in Table 5.

Because it is the global standard, the IAEA data are used, to give a total annual CO_2 emission from electricity generation in Korea of about 192 million tons and the proportions among the various fuel sources are shown in Fig. 2.

CO_2 emission due to coal combustion for power generation is 71.9%, which is nearly double its 36.5% composition of total electricity generation. Therefore, the temporary NCEC was calculated, according to the equation below, as 0.504 tCO_2/MWh.

$$\mathrm{tNCEC} = \frac{(\sum \mathrm{CEC_c} \times \mathrm{EG}_{\,c})}{\text{Amount of total nation's electricity generated}}$$

tNCEC; temporary nation's CO_2 emission coefficient; CEC; individual CEC according to power sources; EG; absolute amount of electricity generated according to power sources; c; Individual power source.

This value is slightly larger than that of traditional value of 0.424 tCO_2/MWh, and was used in the subsequent CO_2 emission calculations. The difference between the NCEC value and individual CEC values is very important in determining quantitatively whether each power source for electricity generation is positive or negative in terms of CO_2 emissions.

4. Amount of CO_2 emissions from the mobile devices

4.1. From mobile wireless electronic devices

Based on all the assumptions previously described, the total annual electricity consumption due to using mobile wireless electronic devices was calculated as 518,194 MWh, equating to 261,411 tons of CO_2 emissions by applying NCEC. The individual

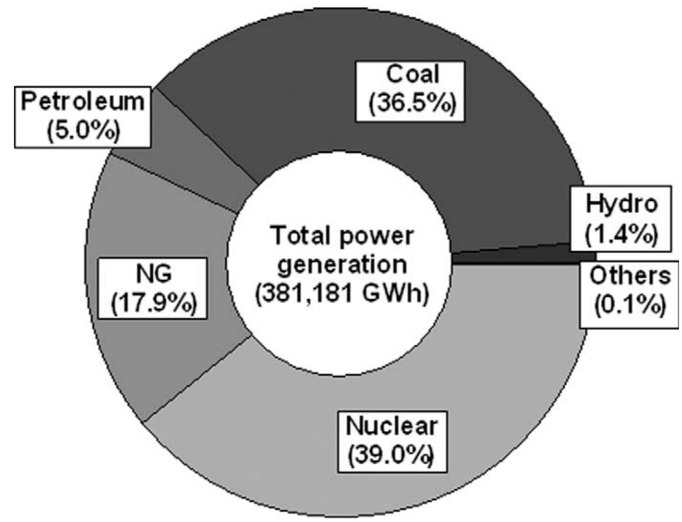

Fig. 1. Total amount of Korea's electricity generation in 2006 and its composition according to fuel sources.

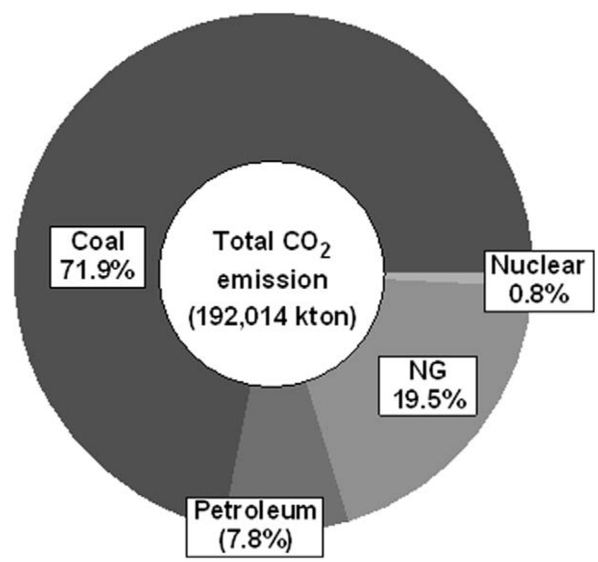

Fig. 2. Total CO_2 emissions from the power generation and their compositions according to fuel sources.

Table 4
Assumptions used to calculate the CO_2 emissions from the electric equipment such as base stations and repeaters for mobile communication services.

Electric equipment	Power output range (kW)	Average power output (kW)	Number of units	Comments
Mobile base stations	2–4	3	60,000	- Including 2 and 3G mobile services
Repeaters	0.01–0.08	0.04	1,800,000	- Including gap-fillers for DMB

Table 5
Korea's electricity generation according to the fuel source in 2006, and individual CO_2 emission coefficients of the electricity power plant.

	Hydro	Coal	Petroleum	NG	Nuclear	Others	Total
Electricity produced (GWh)	5,219	139,205	19,195	68,302	148,749	511	381,181
CO_2 emission coefficient, average,[a] (kg/kWh)	–	0.860	0.689	0.460	0.009	–	–
CO_2 emission coefficient, average,[b] (kg/kWh)	0.008	0.991	0.782	0.549	0.010	0.047	–
CO_2 emission (kton)	42	137,952	15,010	37,498	1,487	24	192,014

[a] Referred to "Korea Electric Power Corporation".
[b] Referred to "International Atomic Energy Agency".

Table 6
Electricity consumption and CO_2 emissions from the mobile communications and portable wireless electronic devices.

Item			Total electricity consumption per year (MWh)	CO_2 emissions per year (ton/year)
Mobile wireless electronic devices	Laptops		425,152	214,277
	2G Phones		20,182	10,172
	3G Phones		46,435	23,403
	Others		26,904	13,560
		Camcorder	1,281	646
		CDP	142	72
		Digital camera	5,694	2,870
		e-book (dictionary)	10,249	5,166
		MP3	2,847	1,435
		PDA	370	187
		PMP	3,473	1,751
		Video game consoles	2,847	1,435
	Total		518,674	261,411 (19%)
Electric equipment for mobile communication services	Mobile base stations		1,876,800	794,707
	Repeaters (including gap-fillers)		630,720	317,883
	Total		2,207,520	1,112,590 (81%)
Total			2,726,194	1,374,002 (100%)

amounts for each device are listed in Table 6 and their compositions are shown in Fig. 3.

Laptops consume 82% of the total energy, followed by 3G phones. The total CO_2 emissions of the other 8 devices were only 5.2% of the total emissions, with an absolute value of 13,560 tCO_2. Their shares are shown in Fig. 4.

The CO_2 emission portion of e-books was estimated as the largest value at 38.1%. This was attributed to the rapid market growth of the e-dictionary, as well as the relatively high power output of the e-book, e-photo album, and e-picture frame.

4.2. From electric equipment for mobile communication services

Annual CO_2 emissions from the electricity required to operate the equipment for mobile communications services was calculated as 1,112,590 tons, which is four-fold greater than that from portable electronic devices. Therefore, the total electricity consumption from mobile devices, including all service equipment and portable devices, was estimated as 2,726,194 MWh, which is 0.7% of the nation's total electricity generation of 381,181 GWh in 2006. This is equal to the amount of electricity generated from a 458 MW thermal power plant with a utilization of 68%. Therefore, the total annual CO_2 emissions from the mobile devices was estimated as 1,374,002 tons, which is 0.24% of the nation's total net CO_2 emissions of 568,400 ktons in 2006 and similar to those from 45 municipal waste solid incinerators in the country. This value equates to 28.6 kg of CO_2 emissions per capita per year in Korea.

5. CO_2 avoidance using renewable energy

As in any other field, the most effective way to avoid the CO_2 emissions from mobile devices is to use electricity produced by almost carbon-free or renewable energy sources. Considering the conditions of mobile devices such as the places where they are used, the level of power output, and battery charging, as well as the status of the renewable energy technologies, solar cell, fuel cell and

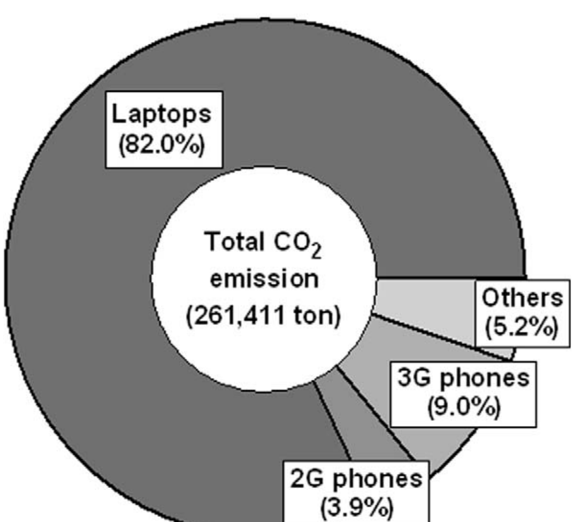

Fig. 3. CO_2 emissions from mobile electronic devices and their compositions.

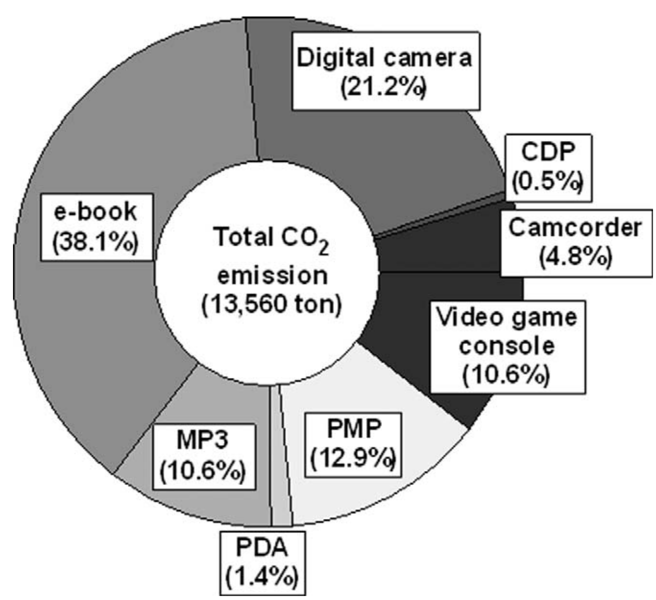

Fig. 4. CO_2 emissions from 8 other portable devices and their compositions.

Table 7
Assumptions used to calculate the CO_2 avoidance using renewable energy as the power supply in mobile devices.

Renewable energy	Using for battery charging for portable devices		Direct using for electric equipment	CO_2 emission coefficient ($kgCO_2/kWh$)
	Battery	Charging efficiency (%)	Efficiency (%)	
Solar cell	Li-ion battery	70	100	0.057[a]
Wind turbine	Li-ion battery	70	100	0.014[a]
MCFC	Li-ion battery	70	100	0.407 [9]
DMFC	–	100	100	0.547 [3]

[a] Referred to "International Atomic Energy Agency".

wind turbine energy could be effective electricity sources in the short and mid-term view. These energy sources have sufficient availability for operation as distributed generation (DG) systems for battery charging and directly electricity supply. For example, the 3 kW of electrical power output required by one mobile base station can be supplied by a solar cell with an array area of approximately 25 m^2. In addition, the electricity produced by a proton exchange membrane fuel cell (PEMFC) or molten carbonate fuel cell (MCFC) in a small-scale DG site could be used for charging mobile phone batteries. Furthermore, the direct methanol fuel cell (DMFC) system could be used as the direct power supply for laptops in place of Li-ion battery.

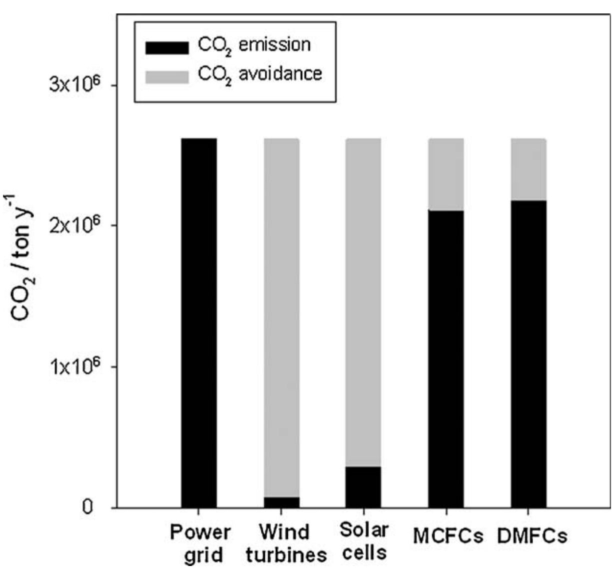

Fig. 5. CO_2 reductions achieved by applying electricity generated from the renewable energy sources to the power supply for charging the batteries of mobile electronic devices.

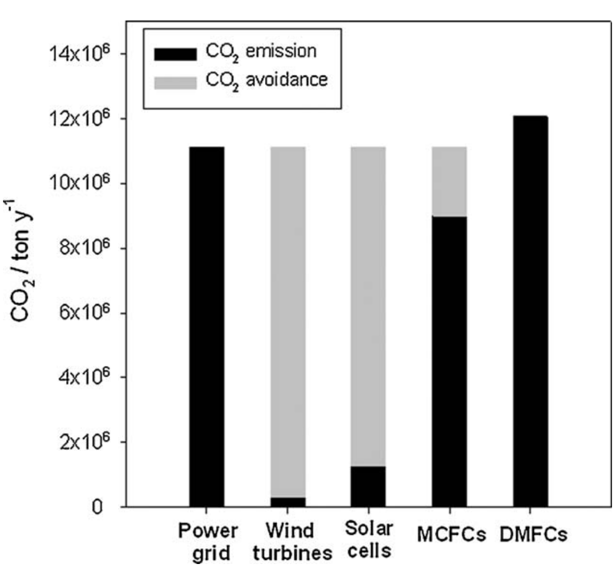

Fig. 6. CO_2 reductions achieved by applying electricity generated from the renewable energy sources to the direct power supply for electric equipment for mobile communication services.

Therefore, the use of these renewable energy sources as power sources to generate the electricity needed for mobile devices will effectively reduce the CO_2 emissions from this field. While the reduction amount is largely dependent on how the renewable energy sources are utilized in the mobile field, the key point is the CO_2 emission coefficients of each individual renewable energy source. These are listed in Table 7.

The CO_2 emission coefficients of solar cell and wind turbine are based on the IAEA data. The CO_2 emission coefficients of MCFC and DMFC are assumed to be 0.407 according to POSCO-Power [9] and 0.547 kg/kWh [3], respectively. However, in the absence of any data on the quantitative contribution to CO_2 emission reduction of the PEMFC systems and as their CO_2 emission coefficient is not reported anywhere, PEMFC systems were omitted in this paper.

Two options are possible to utilize the electricity generated from renewable energy sources for mobile devices: direct supply of the mains electricity to the device and charging the device battery. However, it is assumed that DMFCs are solely used for direct power supply of the devices and equipment. When the electricity produced by these four renewable energy sources is used for battery charging for all mobile or portable electronic devices, their CO_2 avoidances are shown in Fig. 5.

Solar cell and wind turbine offer CO_2 emission savings of about 87% and 97%, respectively, compared to traditional sources, when used to supply mobile electronic devices. However, the MCFC and DMFC systems only slightly reduced the CO_2 emissions. Although the CO_2 emission coefficient of DMFC, 0.547 kg/kWh, is higher than the NCEC, 0.504 kg/kWh, the DMFC system can reduce the CO_2 emissions from the portable electronic devices by 17% because it can be used for the direct power supply of the devices in place of battery power. Therefore, the efficiency gain results from the avoidance of any electricity loss due to battery charging.

Assuming that the electricity generated from the four renewable energy sources is used as direct power supply for electric equipment to support mobile communication services, the CO_2 emission reductions are larger than those of the mobile devices themselves, as shown in Fig. 6.

This is because that there is no energy loss due to direct use of electricity without battery charging. The energy loss caused by charging battery was assumed to be 30%, which leads to unnecessary CO_2 emissions in mobile devices. On the other hand, the use of the DMFC system for direct power supply to electric equipment would release 8% more CO_2 emissions than those emitted by using mains electricity, which equates to the difference of the CO_2 emission coefficient ratio of the DMFC system and the estimated NCEC. Therefore, the DMFC system is not advantageous compared to traditional power supply in the equipment for mobile communication in terms of CO_2 emission reduction. However, the other advantageous features of the DMFC system can compensate for this loss.

6. Conclusions

The present paper has analyzed the CO_2 emissions from Korean mobile electronic devices based on various assumptions. The quantitative and qualitative contributions to CO_2 emission reduction achieved by substituting four renewable energy sources, solar cells, wind turbine and two fuel cells, for traditional electricity generation are also investigated. The conclusions are as follows.

- For calculation, the NCEC value was temporarily estimated as 0.504 tCO_2/MWh based on Korea's electricity production according to the fuel source, and individual CEC values released by IAEA.
- The total amount of annual CO_2 emissions from the mobile devices was calculated as approximately 1.4 million tons, which is 0.24% of nation's total net CO_2 emission and equates to 28.6 kg of CO_2 emissions per capita in Korea.
- CO_2 emissions from the portable wireless electronic devices and electric equipment for mobile communication were calculated as about 0.3 and 1.1 million tCO_2, respectively.
- Using the renewable energy sources of solar cell and wind turbine for battery charging of mobile or portable electronic devices will reduce CO_2 emissions by about 87% and 97%, respectively. However, the use of MCFC and DMFC systems will only slightly reduce the CO_2 emissions.
- Using renewable energy sources for direct power supply to electric equipment for mobile communication, the CO_2 emission reduction achieved by wind turbine, solar cell and MCFC is slightly larger than that for the devices themselves due to the avoidance of any energy loss due to battery charging. However, the DMFC system would release 8% more CO_2 emissions than those emitted by using mains electricity.

Acknowledgements

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